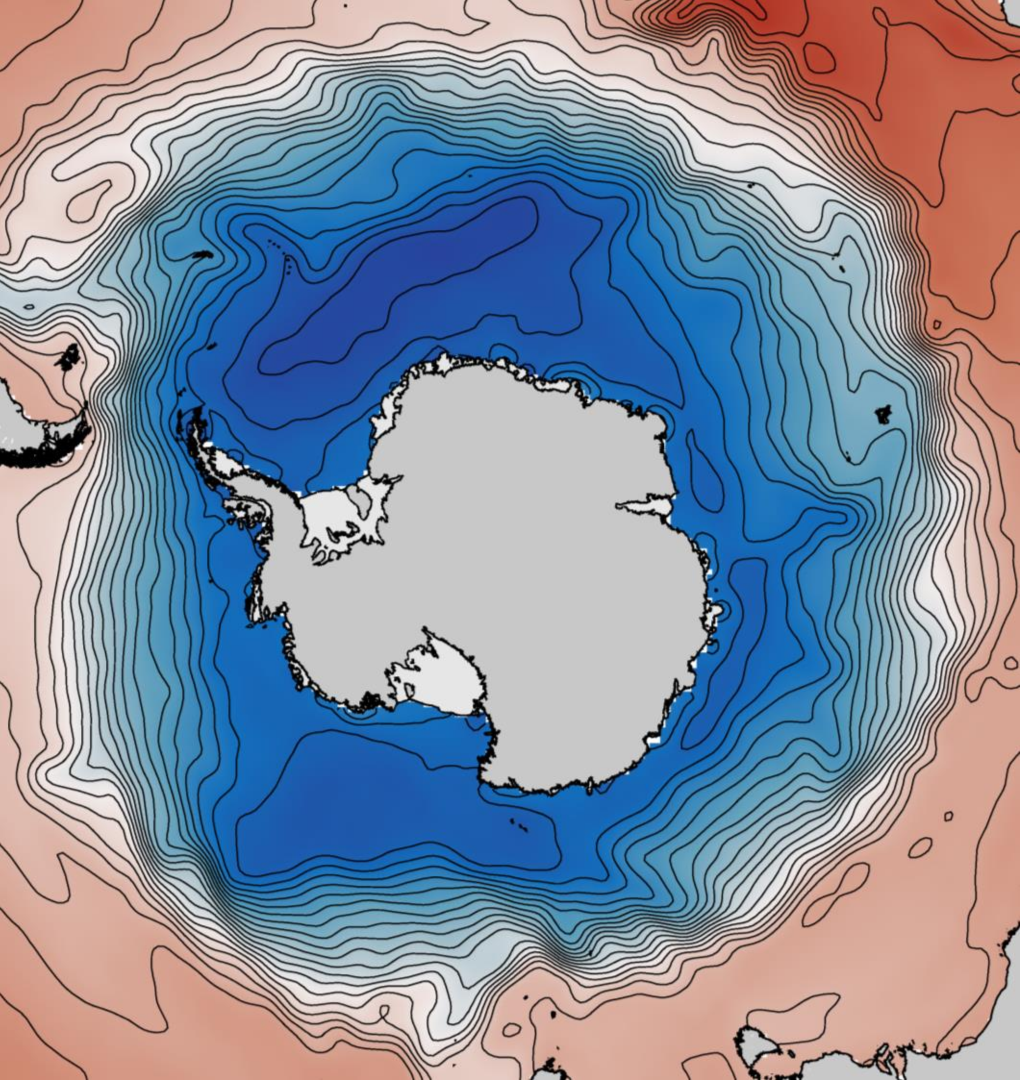

Dynamic topography and sea level anomalies of the Southern Ocean:

Variability and teleconnections

Tom W. K. Armitage, Ron Kwok, Glenn Cunningham

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Andrew F. Thompson

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Caltech

Jet Propulsion Laboratory
California Institute of Technology

Talk outline

1. Introduction
   - The Southern Ocean
   - Circulation in Antarctic marginal seas
   - The Antarctic Slope Current
2. Methods
   - Sea level in ice-covered regions
   - Basin-wide composites
3. Results
   - Mean DOT and circulation
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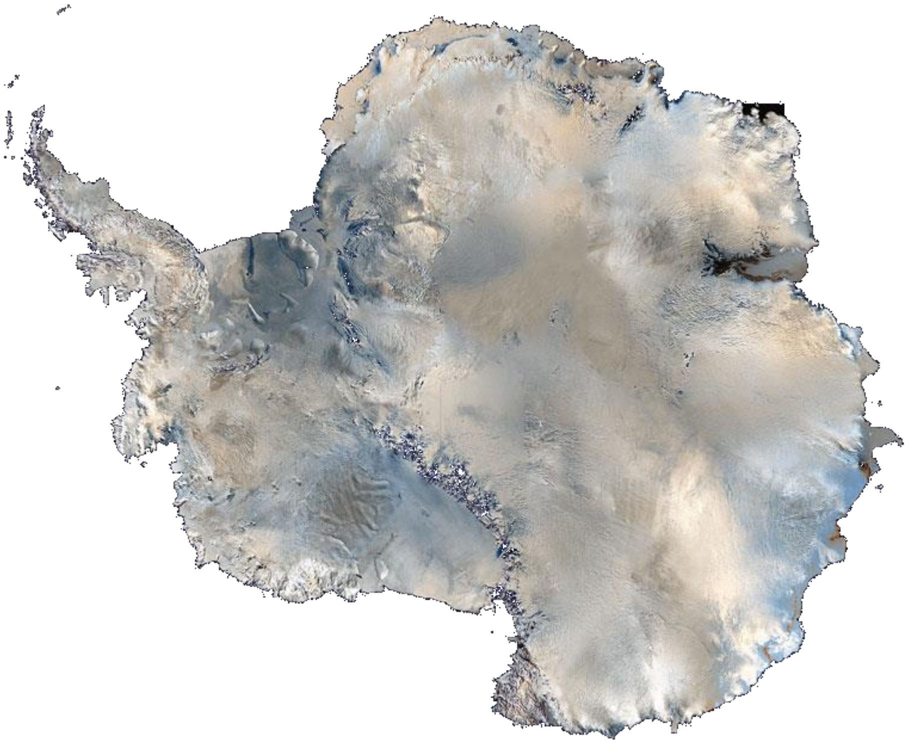
   - Ross/Weddell gyre variability
   - Climate forcing



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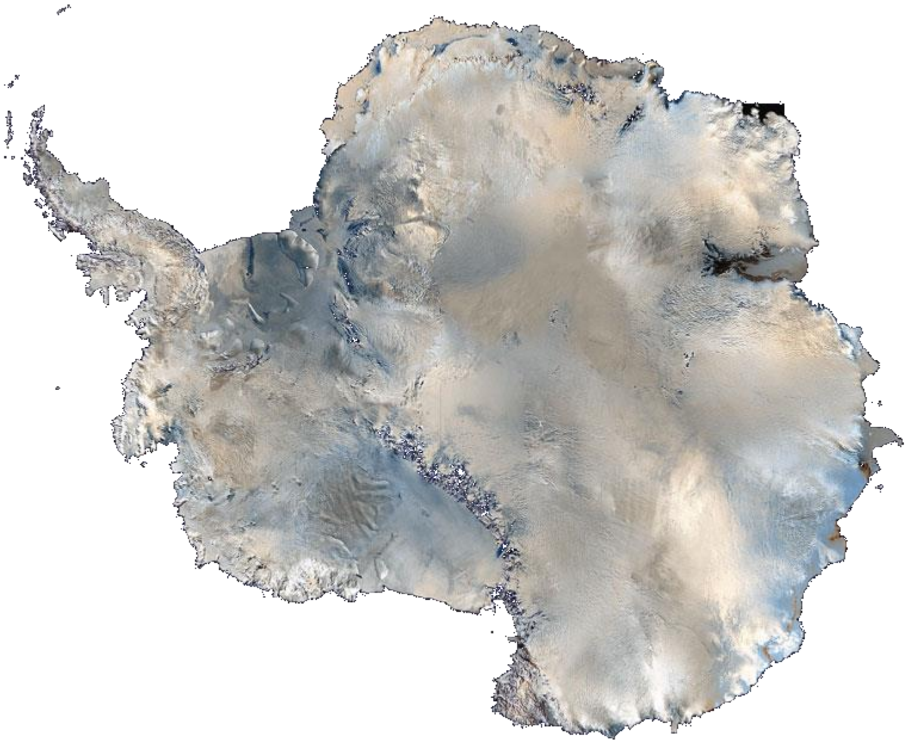

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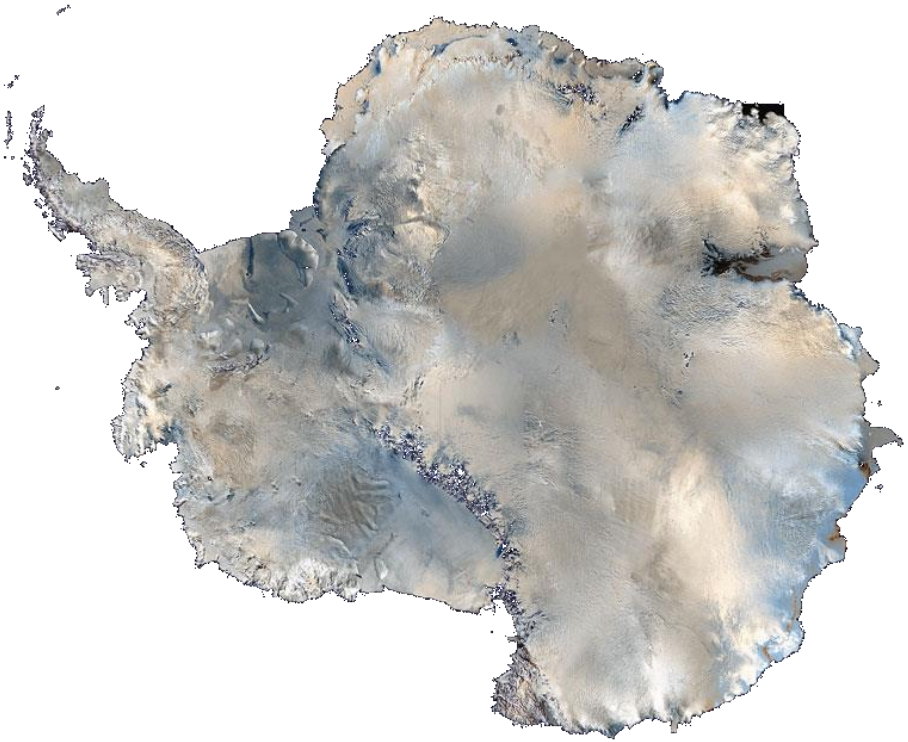

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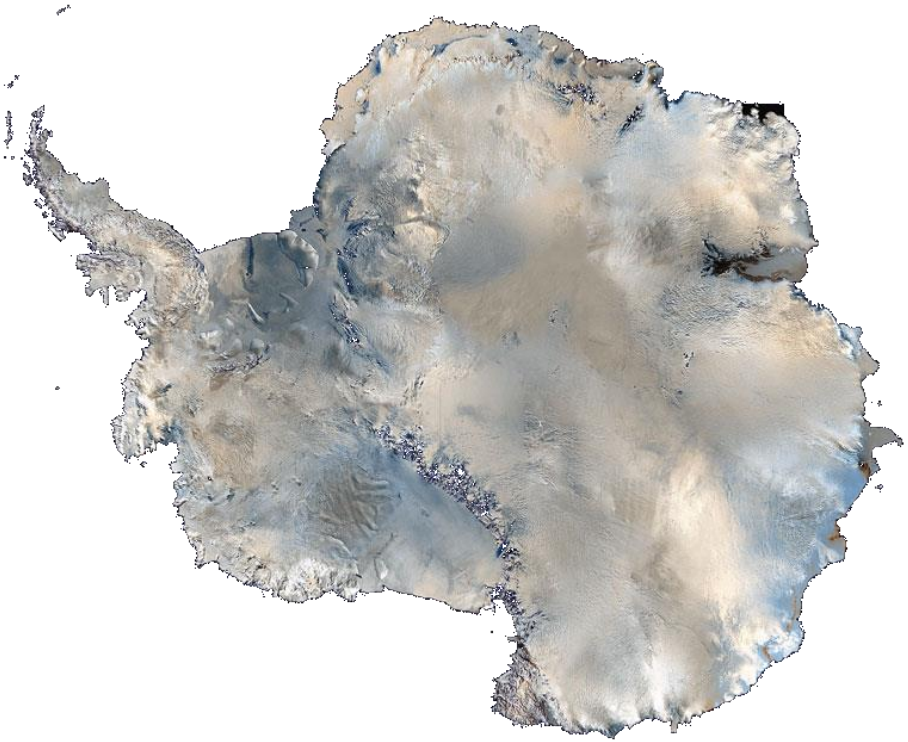
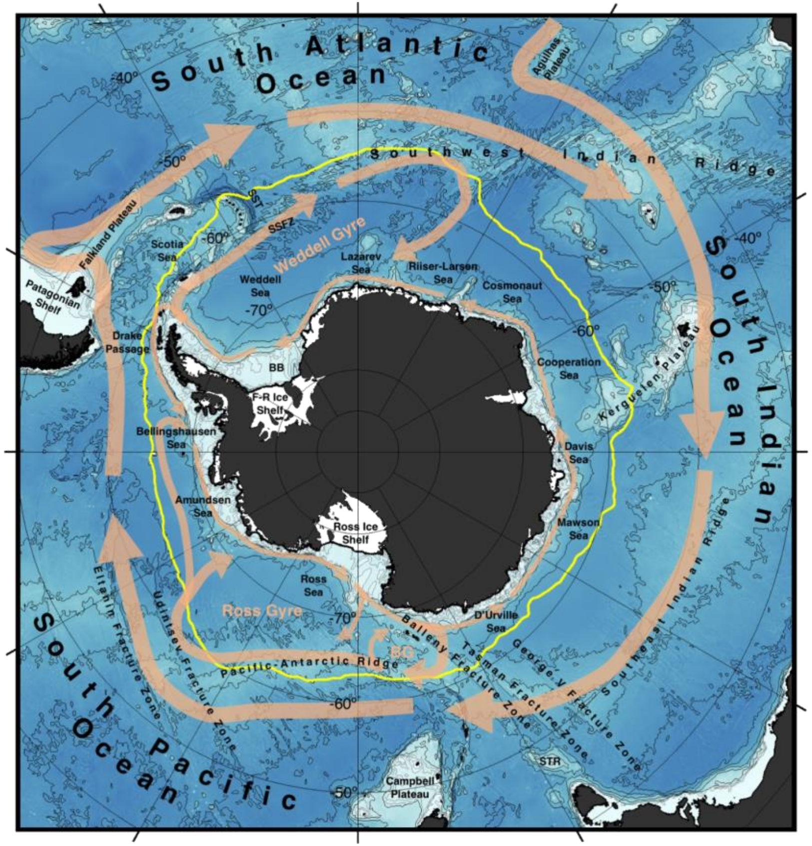


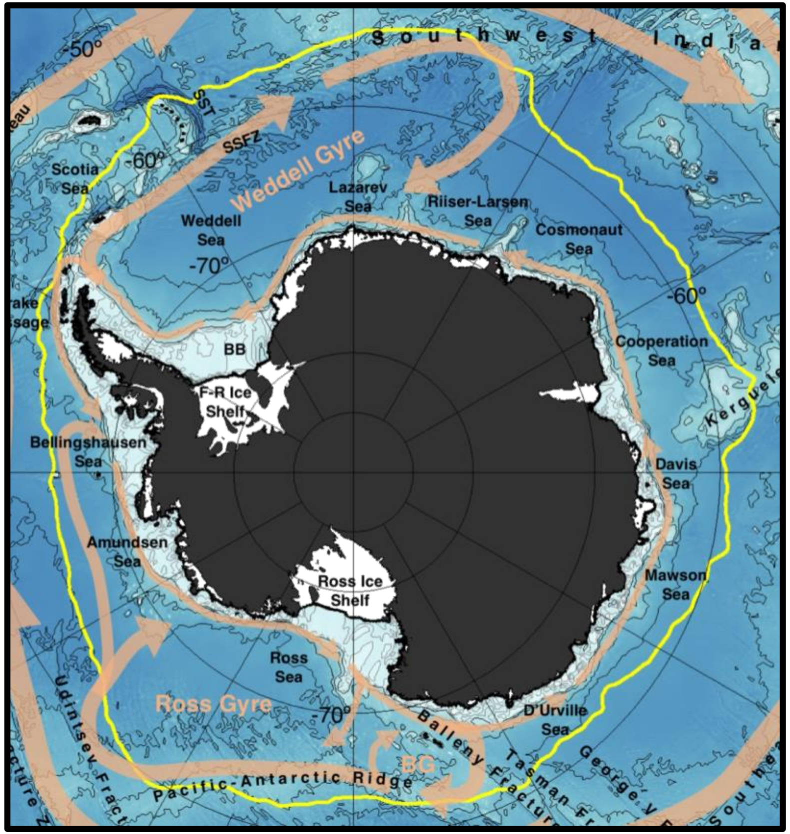
Introduction: The Southern Ocean

- Encircles the Antarctic continent
  - Atlantic (Drake Passage – 20ºE)
  - Indian (20ºE - 150ºE)
  - Pacific (150ºE – Drake Passage)
- Absence of land 56ºS - 61ºS
  - Westerly wind stress + surface buoyancy forcing
  - Formation of the westerly Antarctic Circumpolar Current
  - Transports up to 170 Sv

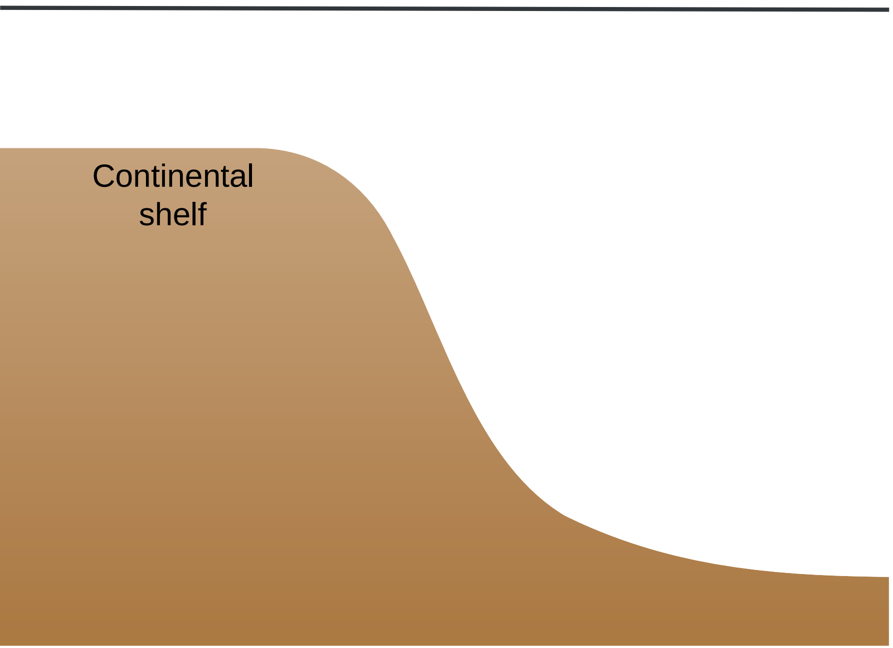


Introduction: Circulation in the Antarctic margins

- Near-shore easterlies
  - Coastal Ekman convergence
  - Sea level set up
  - Easterly Antarctic Slope Current
- Ross/Weddell Gyres
  - Cyclonic (upwelling) gyres
- Typically difficult to observe
  - sea ice, inaccessibility
- ASC, gyres, ice-covered for at least part of the year



Introduction: The Antarctic Slope Current



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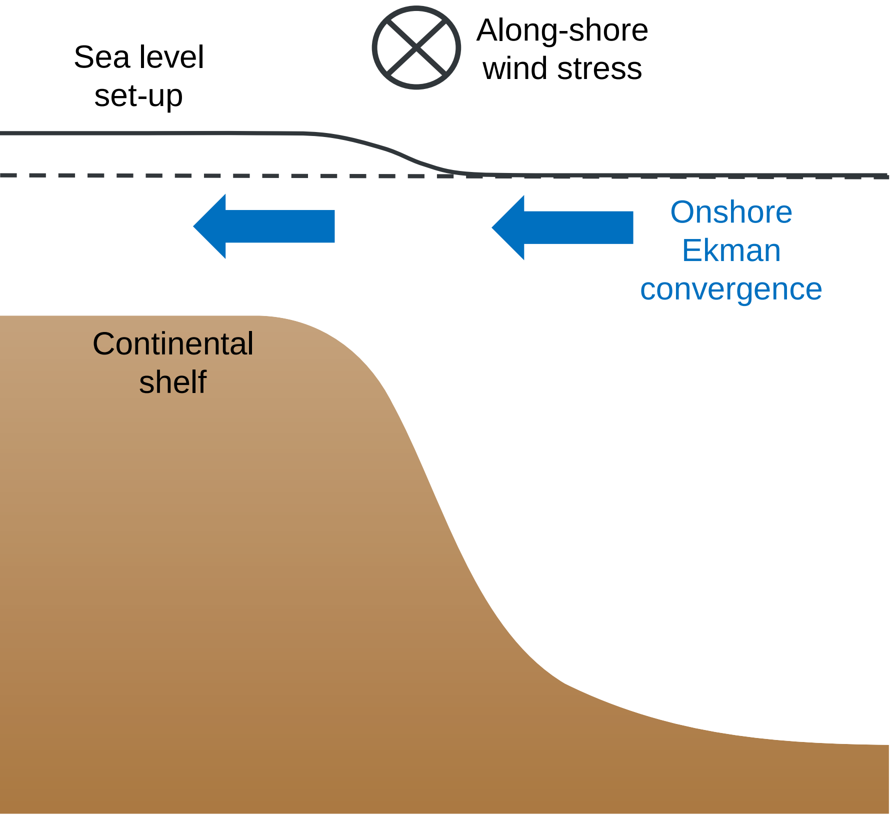
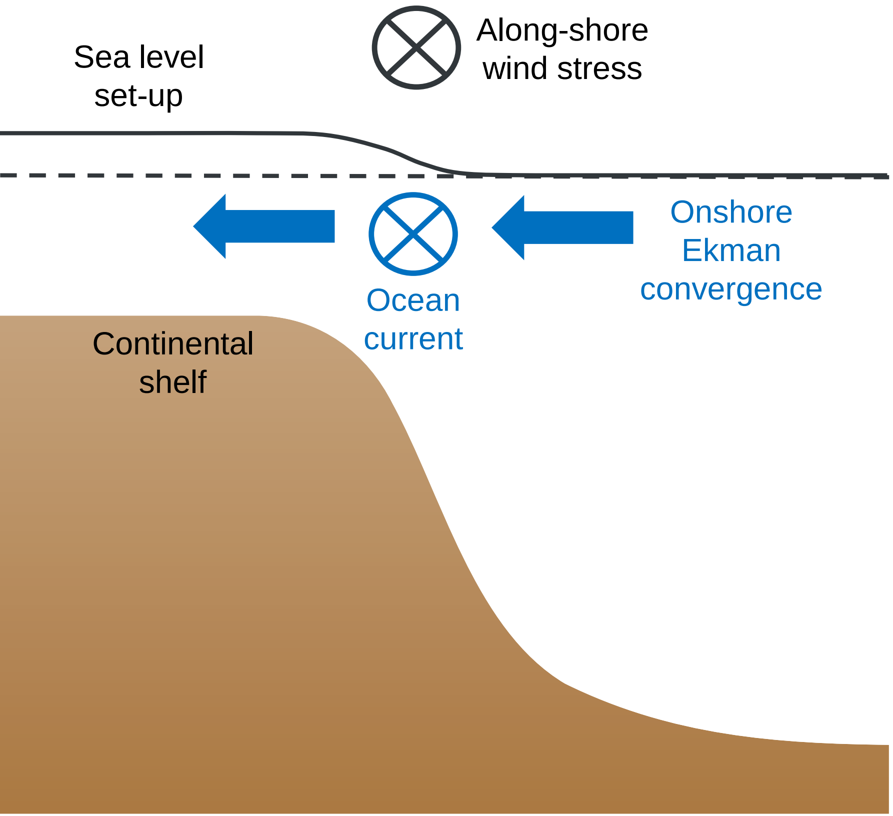


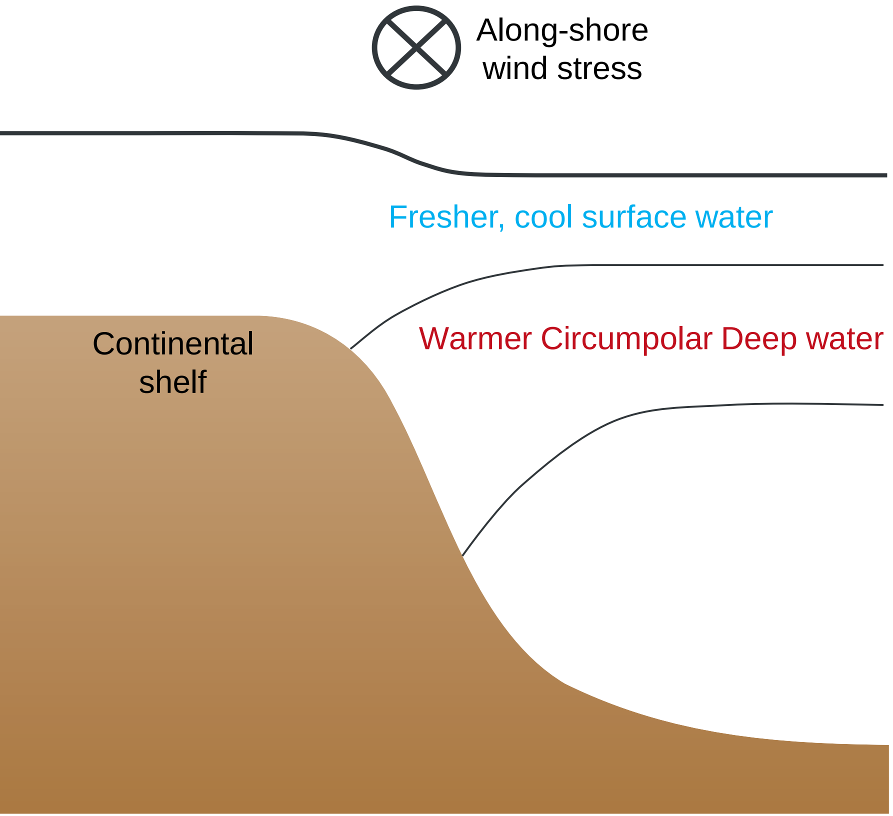
- Along-shore wind stress
  - Ekman transport to the left
  - Sea level set-up against the coast

Introduction: The Antarctic Slope Current



- Along-shore wind stress
  - Ekman transport to the left
  - Sea level set-up against the coast
- Resulting sea level tilt leads to along-shore ocean current
  - The Antarctic Slope Current

Introduction: The Antarctic Slope Current



- Along-shore wind stress
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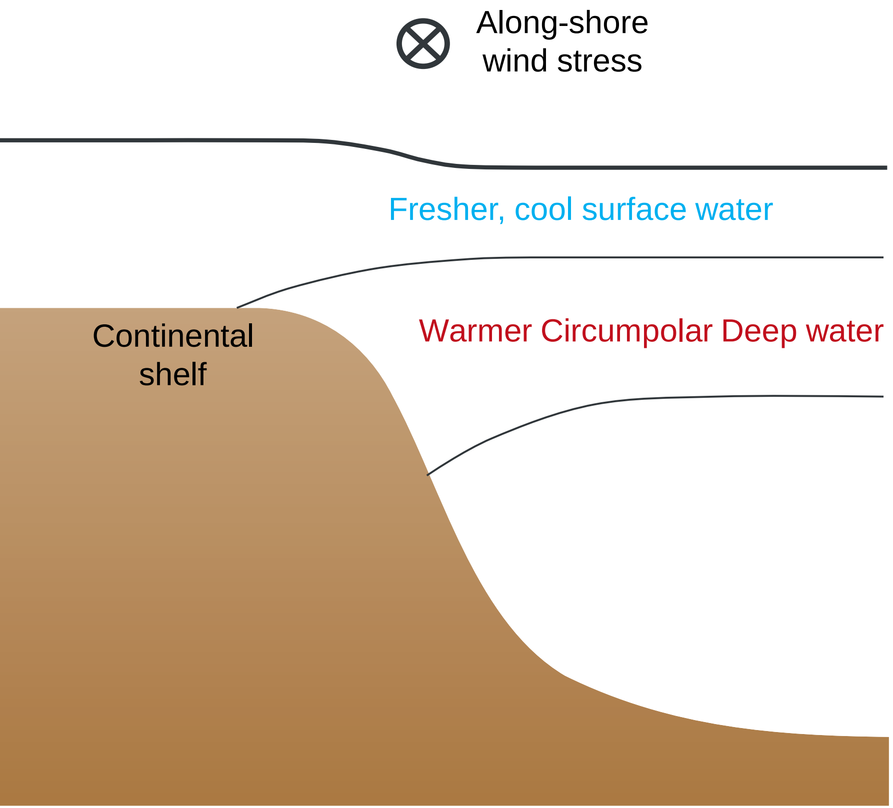
  - Sea level set-up against the coast
- Resulting sea level tilt leads to along-shore ocean current
  - The Antarctic Slope Current
- Downwelling of interior density surfaces
- Modulates access of CDW onto the continental shelf
- Implicated in ice shelf melt

Introduction: The Antarctic Slope Current



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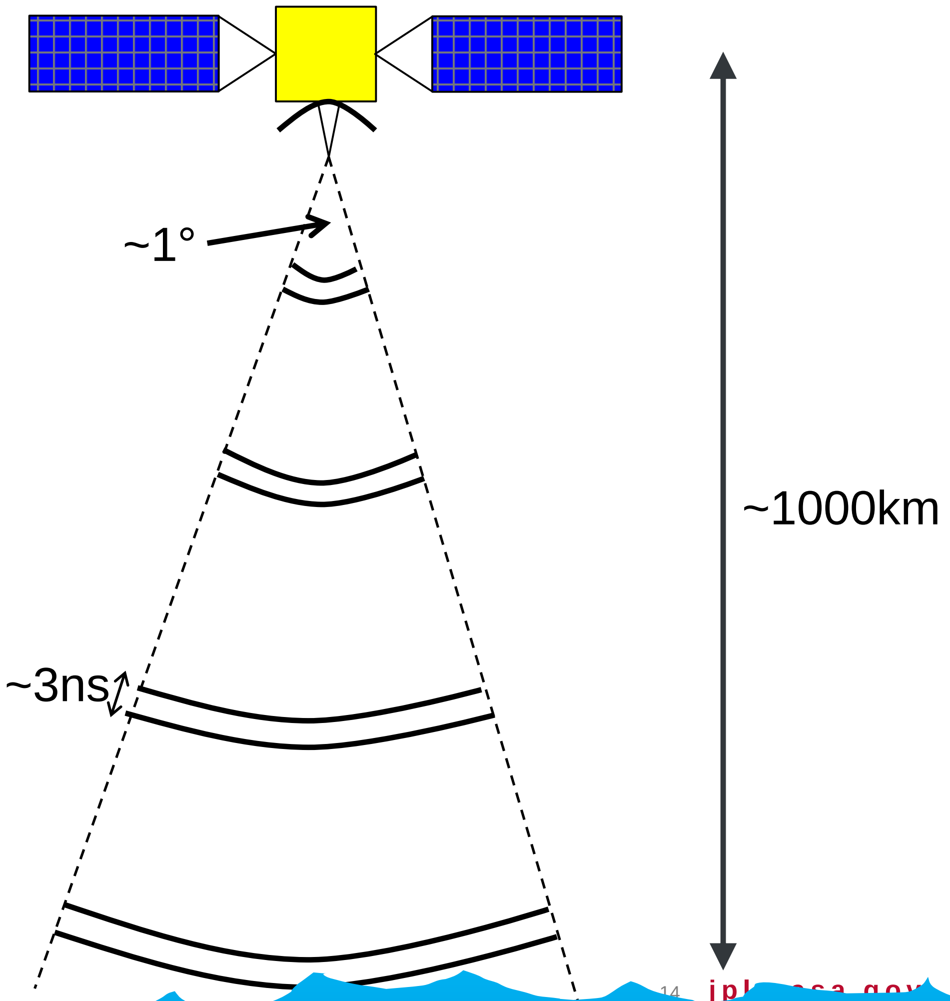
- Modulates access of CDW onto the continental shelf
- Implicated in ice shelf melt

Motivation

- Want to examine seasonal to interannual variability in Antarctic marginal seas
  - Antarctic Slope Current
  - Ross/Weddell Gyre
- Sea level a good diagnostic measurement
  - Conventional processing limited by ice cover
- Can use specialised processing in ice-covered regions, combine with conventional open ocean sea level

Method: Radar altimetry

- Satellite orbiting at ~1000km
- Emit radar pulses towards the surface



Method: Radar altimetry

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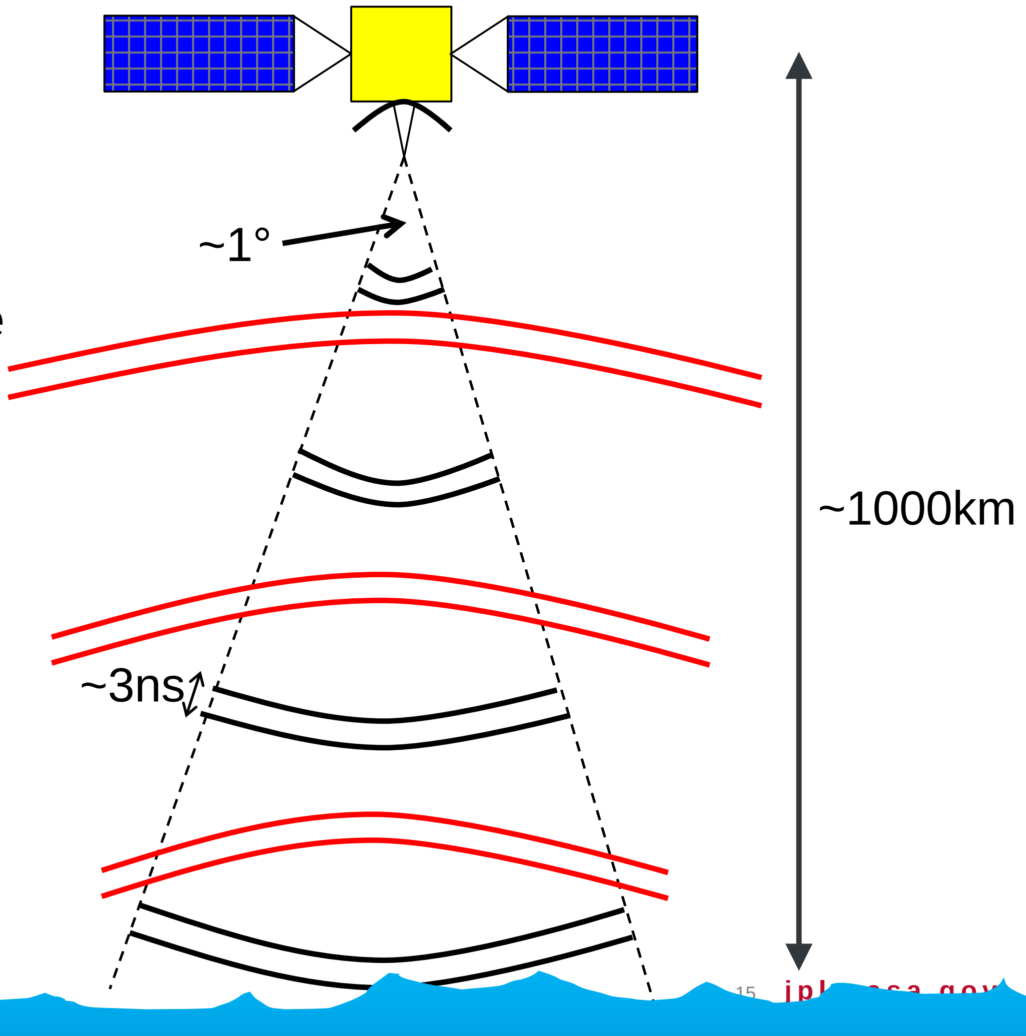
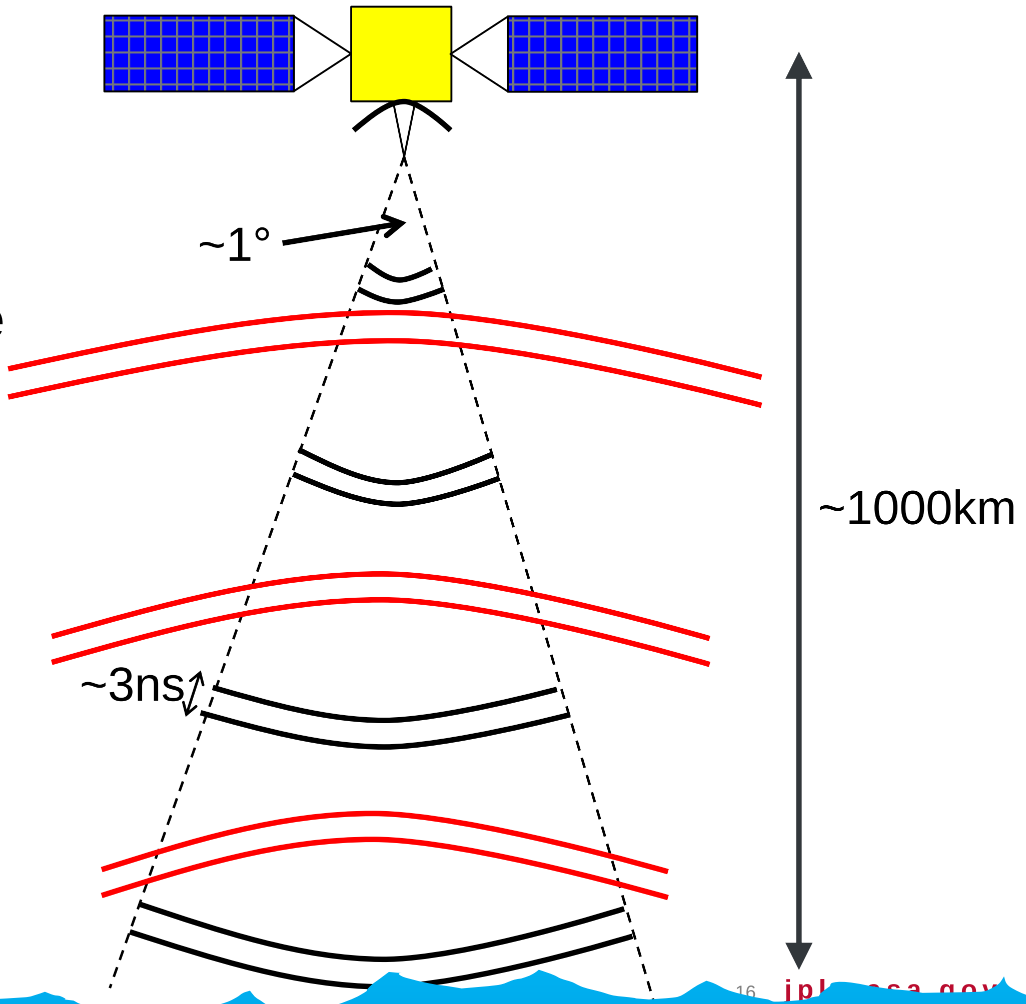


Method: Radar altimetry

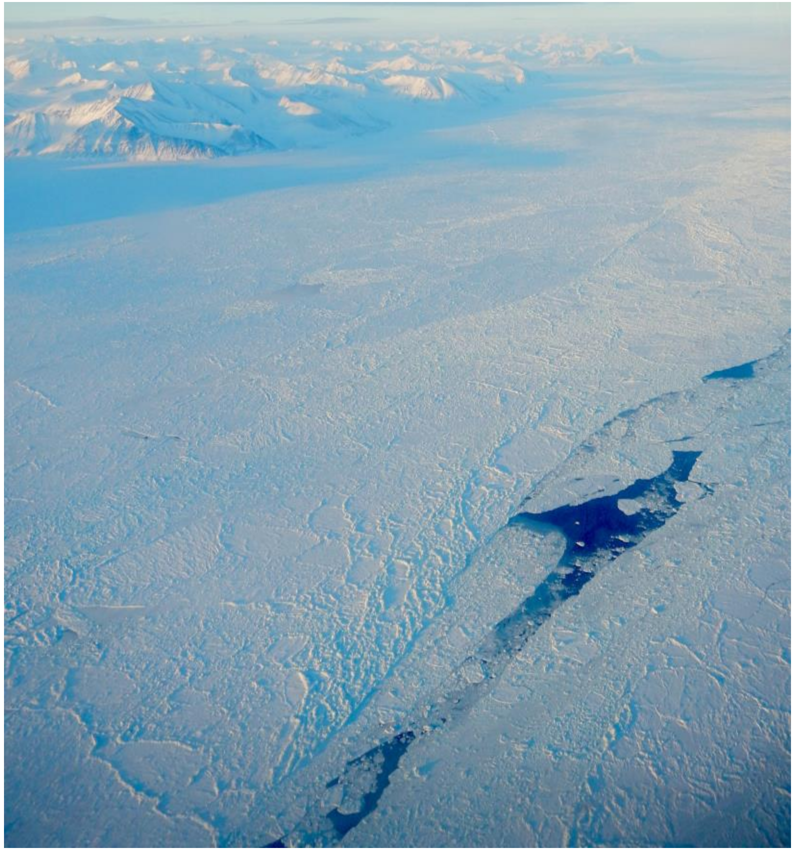
- Satellite orbiting at ~1000km
- Emit radar pulses towards the surface
- Receive the reflected pulses and estimate the two-way travel time, convert to range
- Combine this with:
  - Satellite altitude
  - Geophysical corrections

→ Get sea surface height



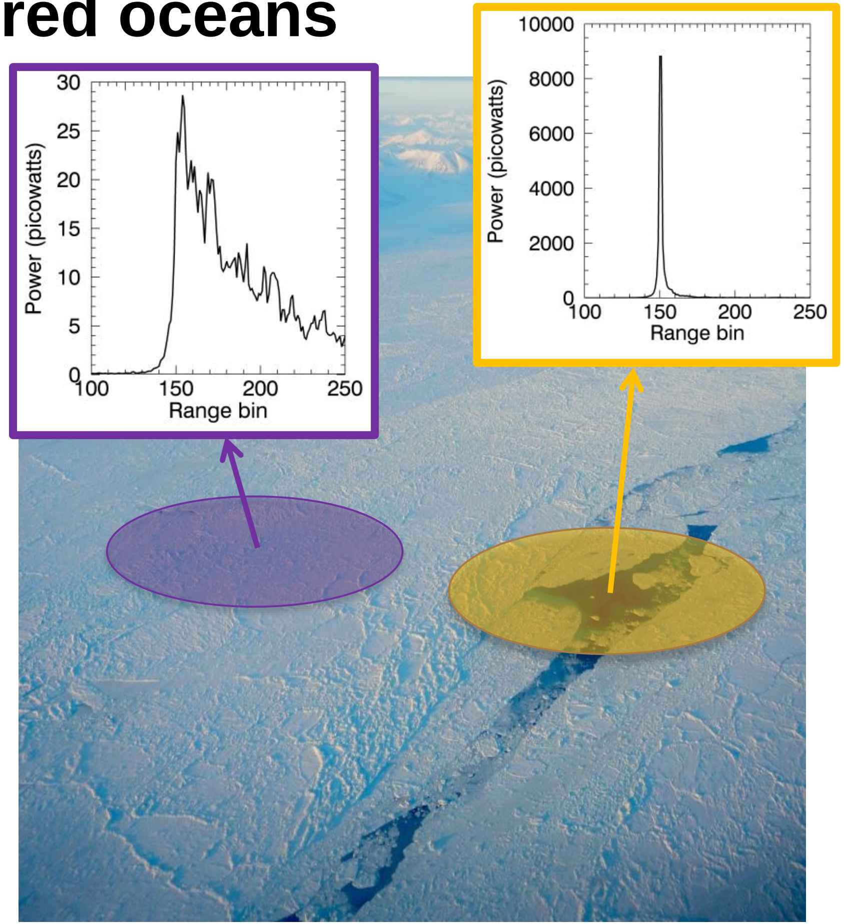
Method: Sea level in ice-covered oceans

- Conventional processing fails in the presence of sea ice
- Surface scattering is highly inhomogeneous
  - Leads appear very bright (mirror-like)
  - Ridges/deformation features

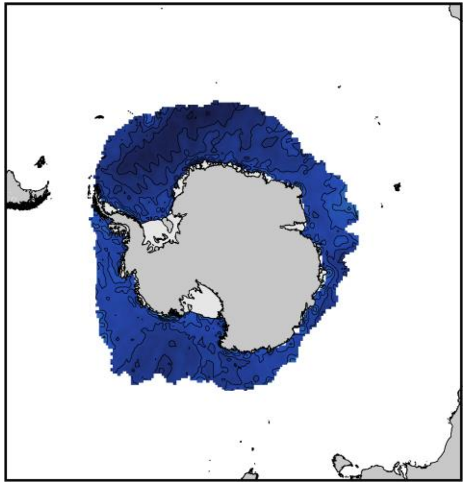


Method: Sea level in ice-covered oceans

- Conventional processing fails in the presence of sea ice
- Surface scattering is highly inhomogeneous
  - Leads appear very bright (mirror-like)
  - Ridges/deformation features
- Have to identify returns from openings to estimate SSH
- Can do this based on received pulse properties



Method: Southern Ocean sea level composites



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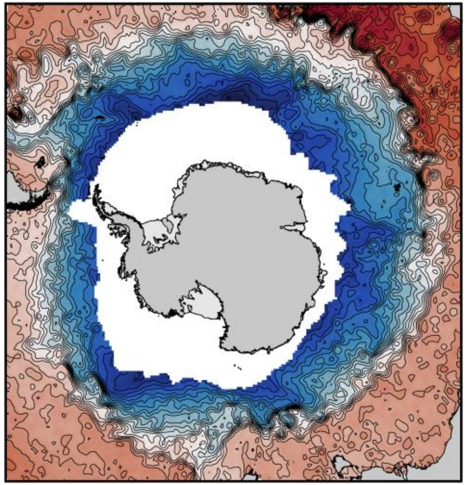

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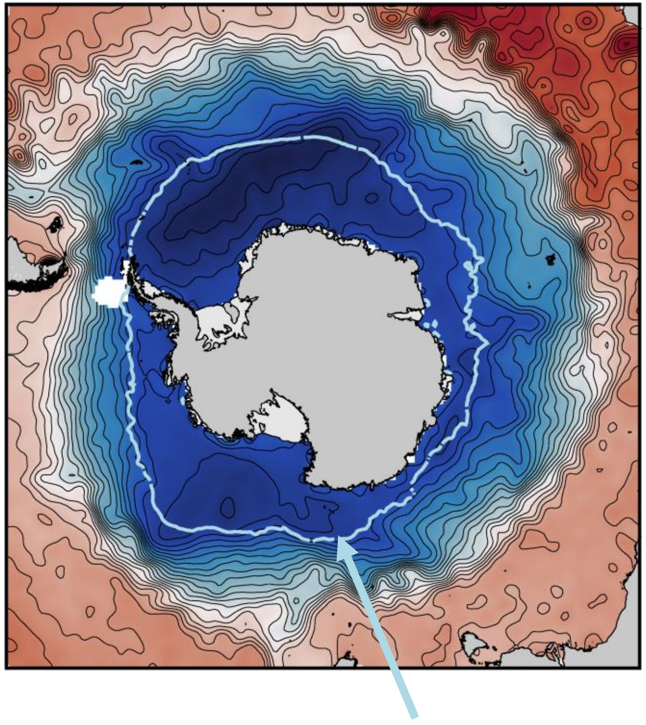

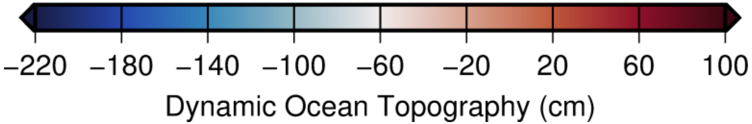

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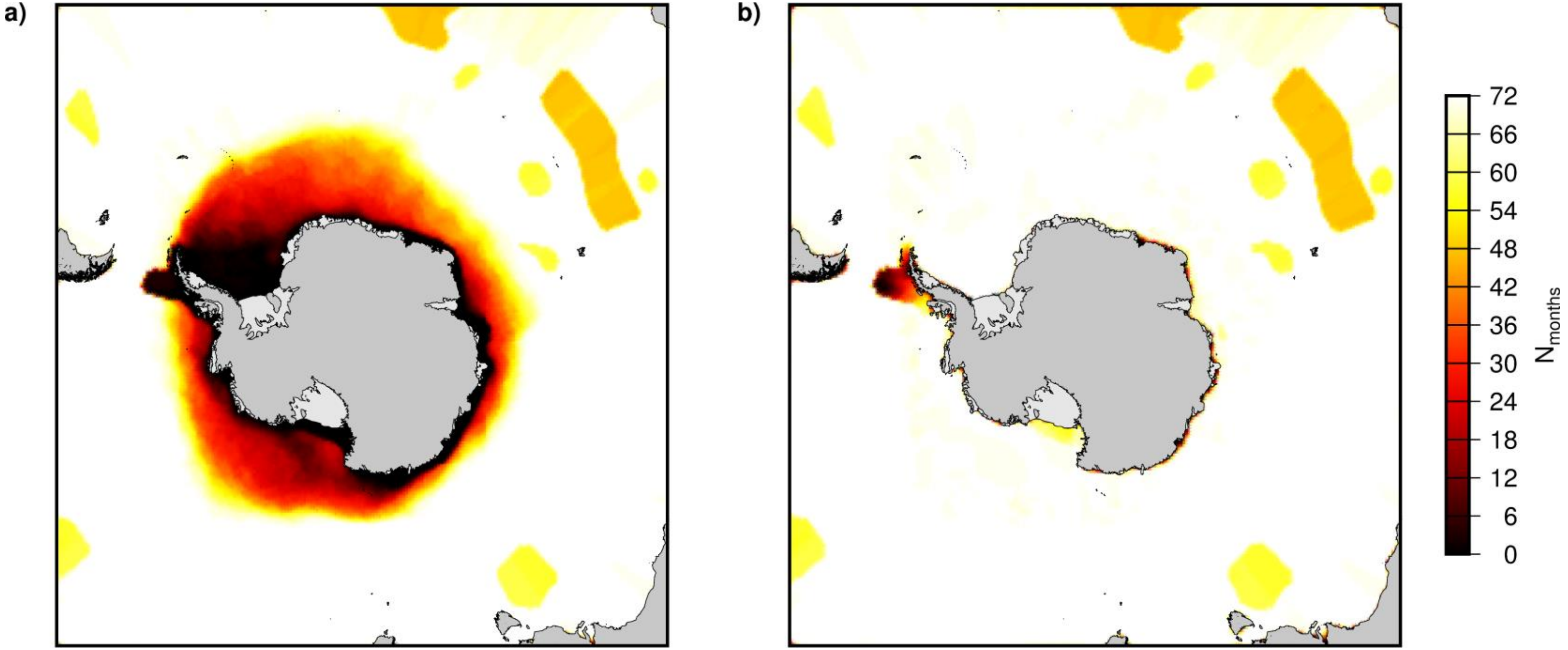
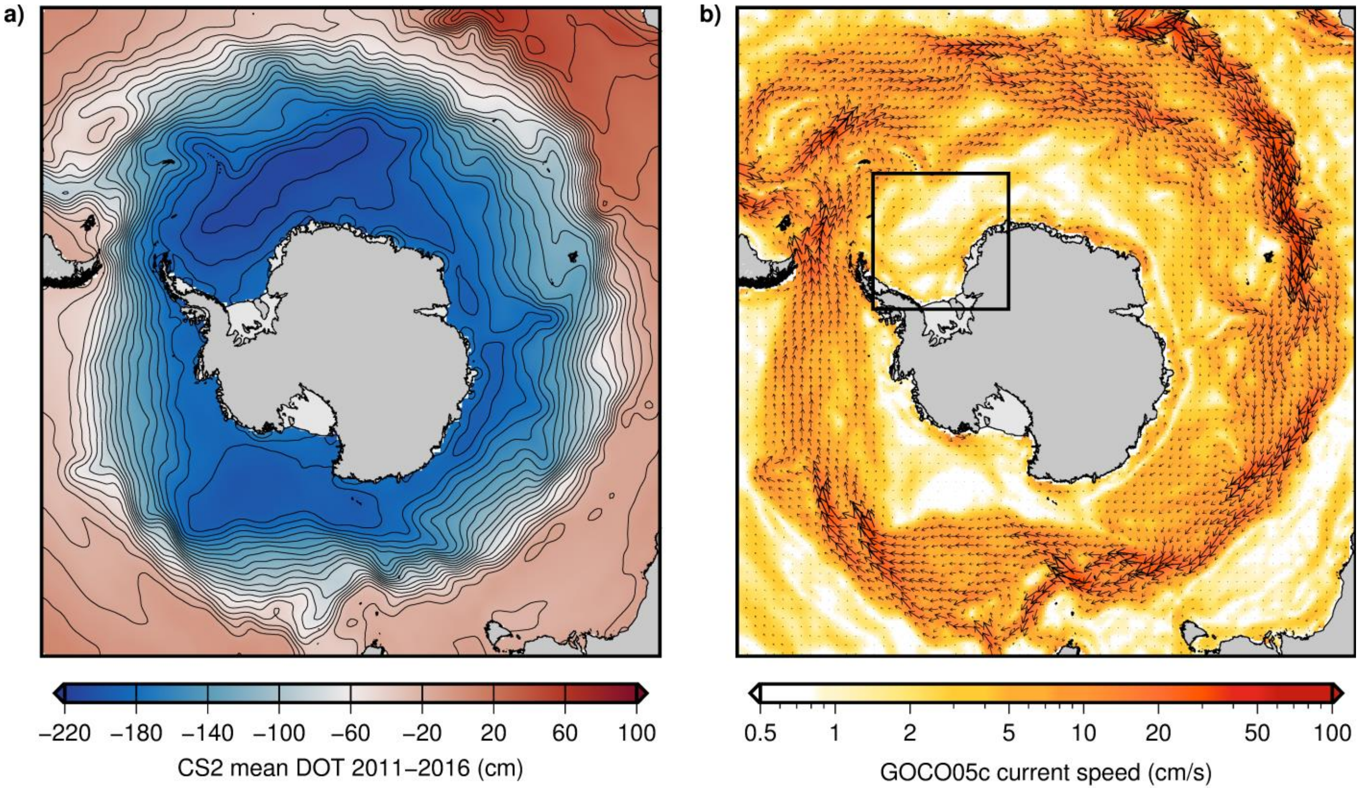


Use CryoSat-2; 2011-2016; monthly resolution; 50km grid

Results: Mean DOT and circulation



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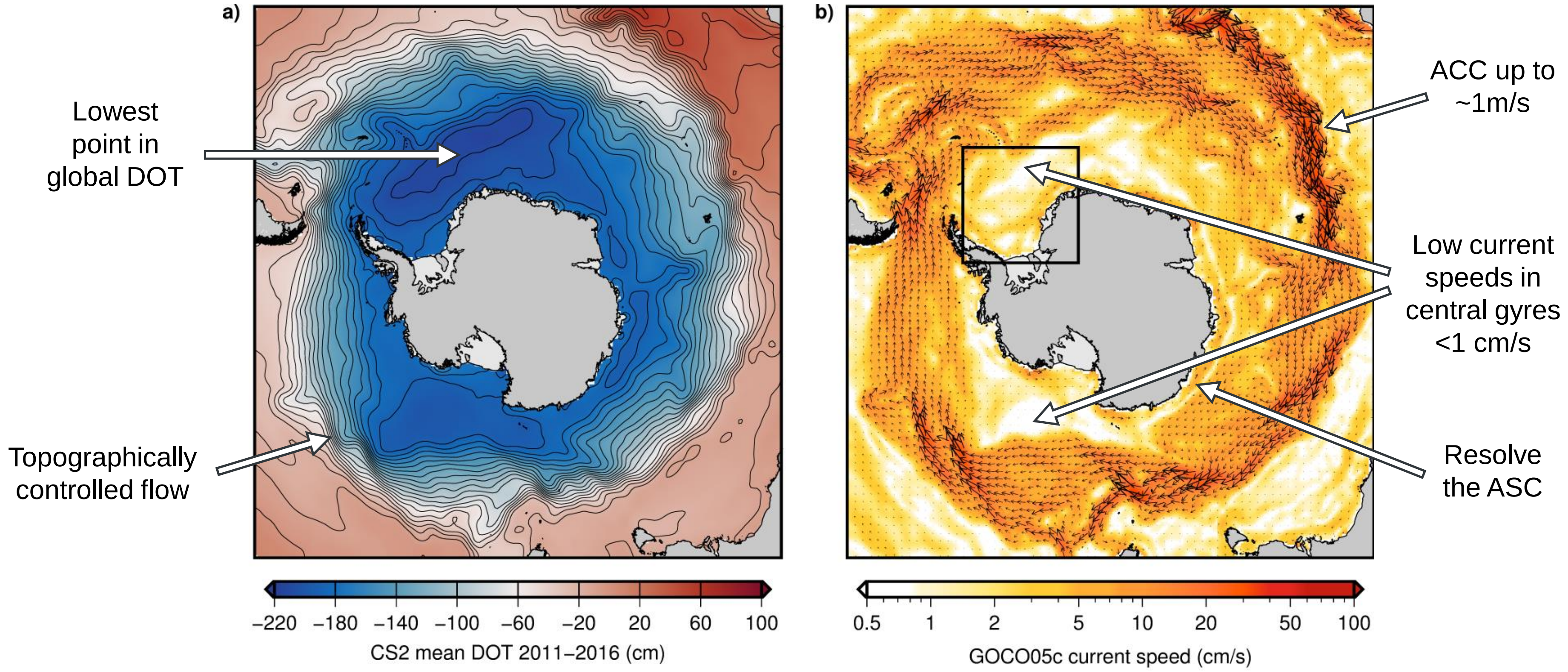
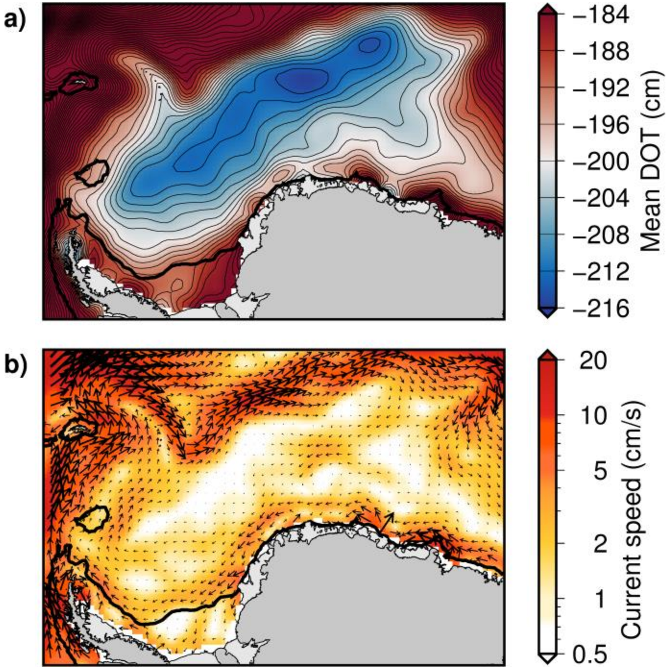
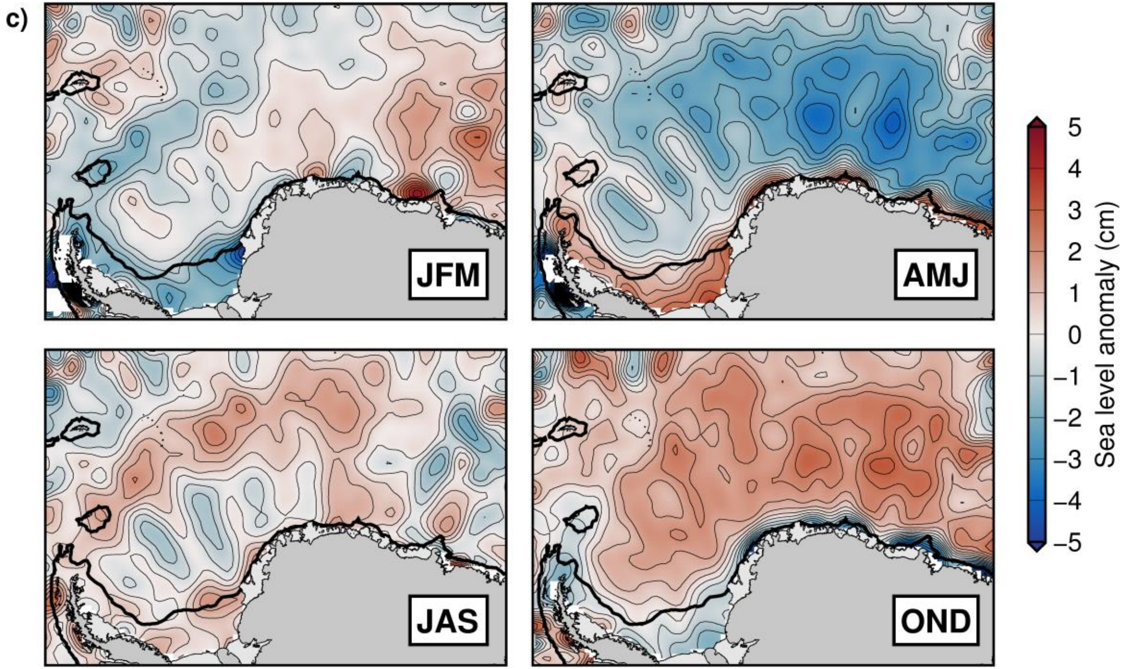


Results: Seasonal variability

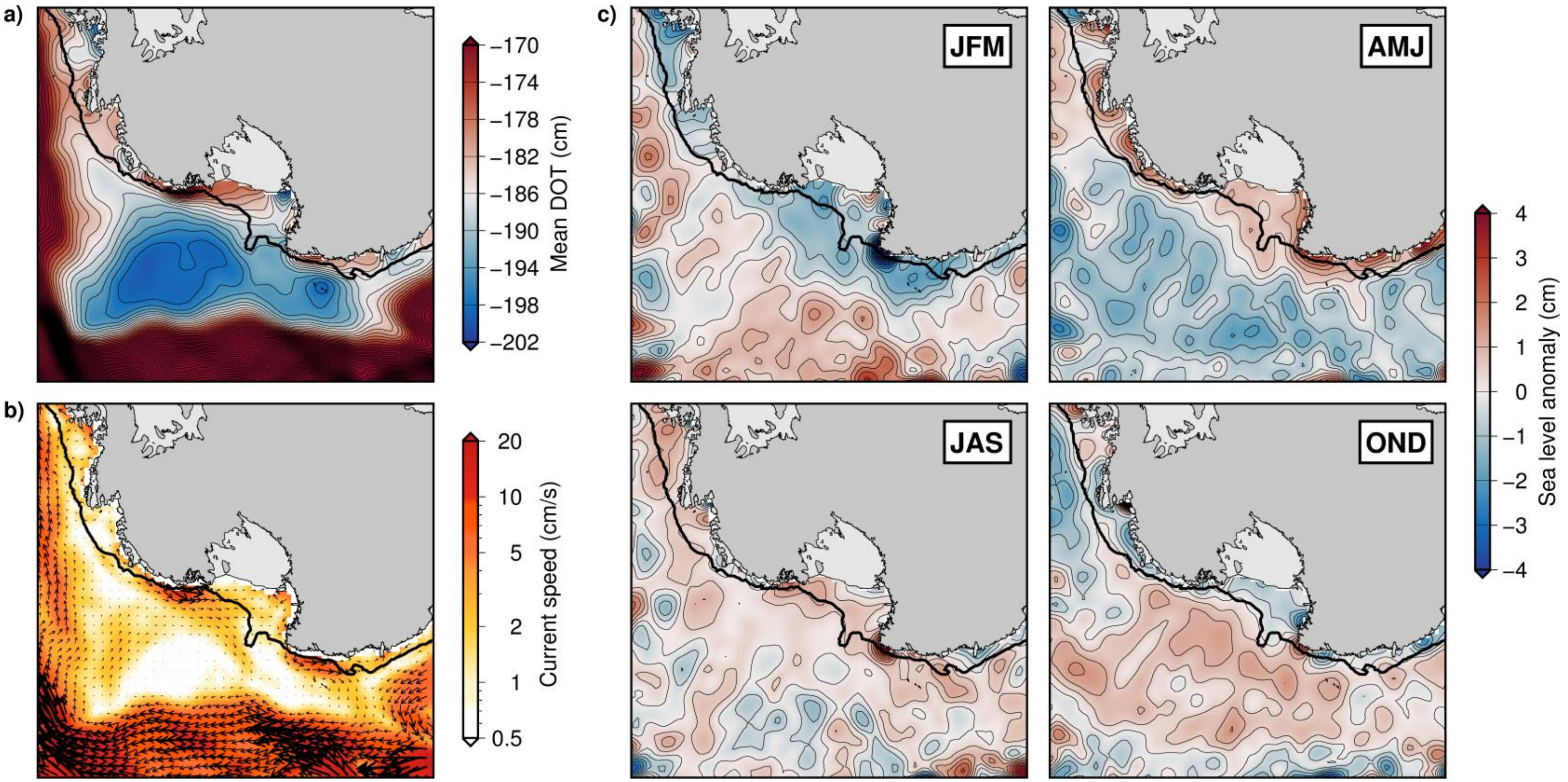


Mean circulation

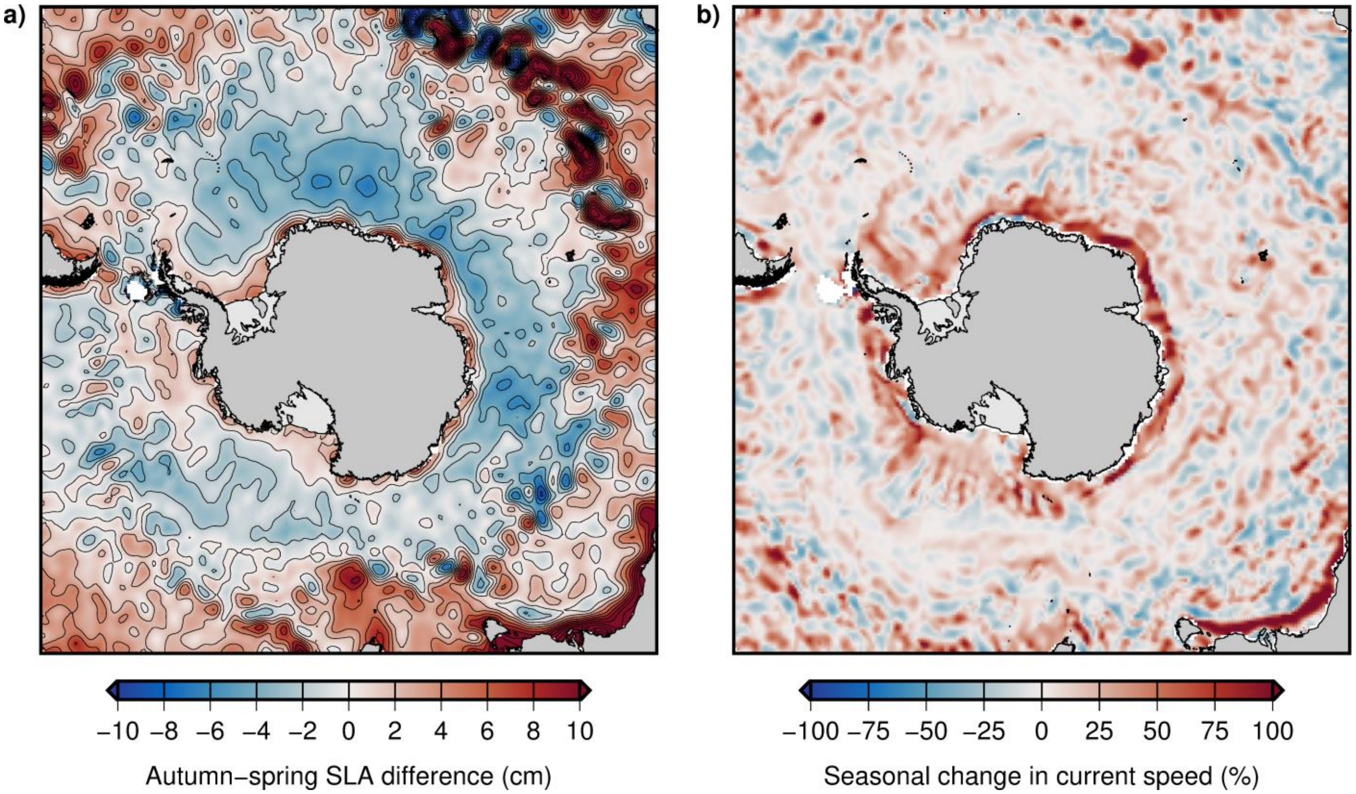


Seasonal anomalies

Results: Seasonal variability

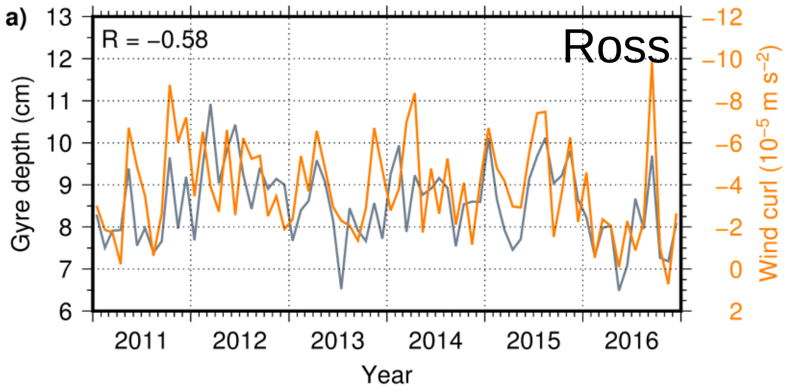


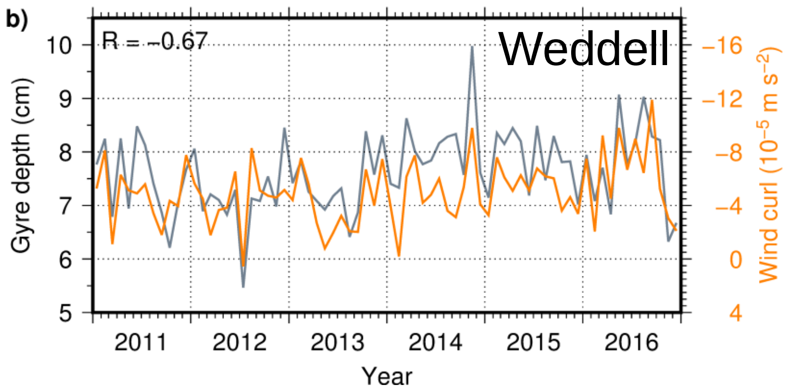
Results: Seasonal variability



Results: Ross/Weddell Gyre variability

- Gyre circulation strength is well correlated with (nonseasonal) wind curl
  - In turn weakly correlated with SAM





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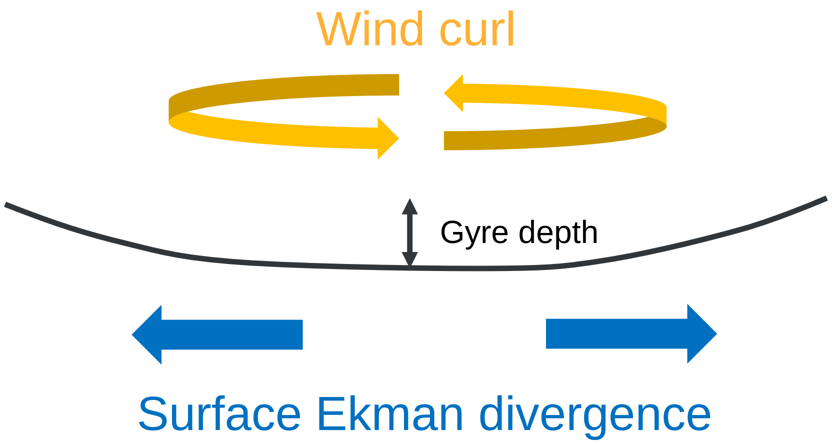

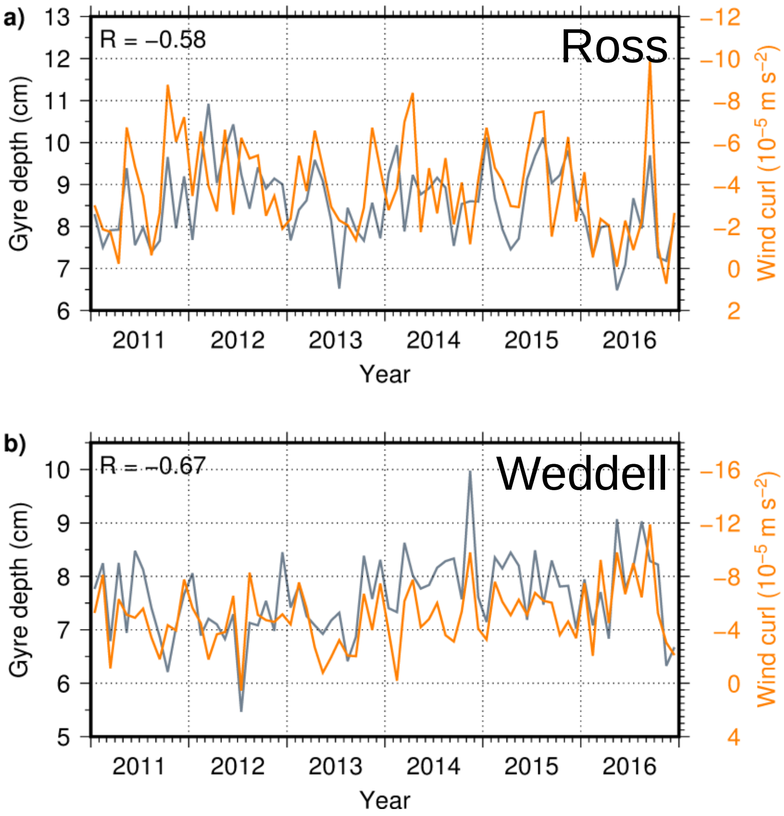

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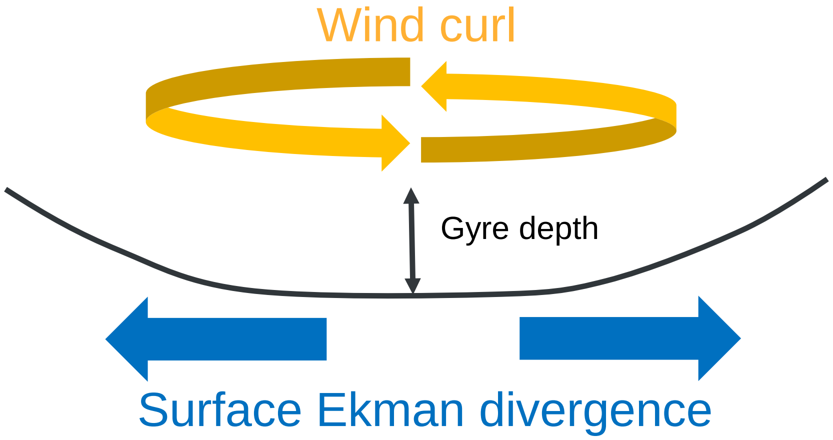
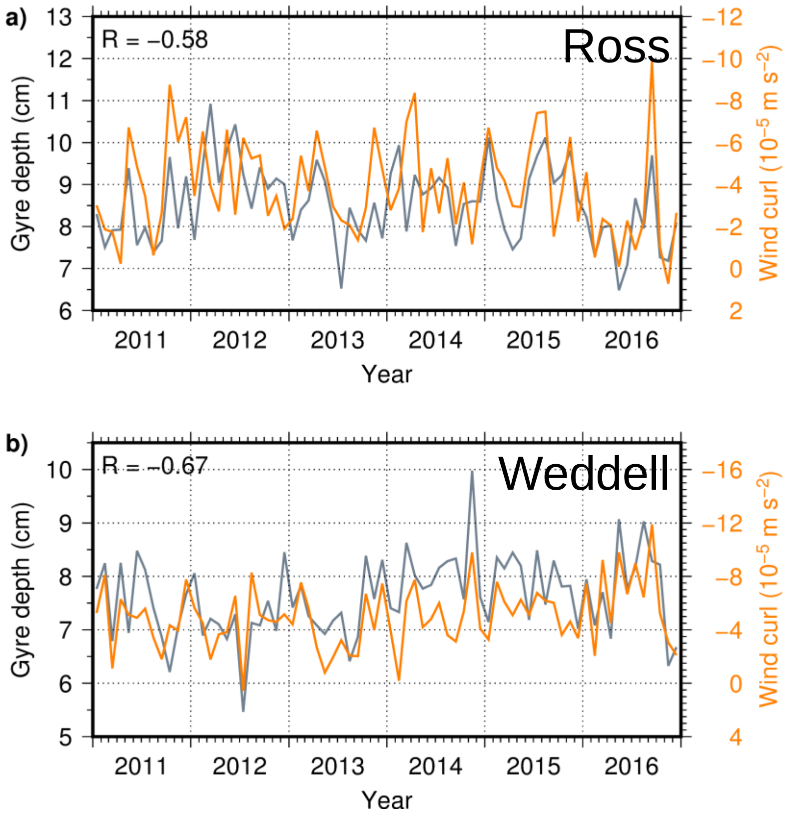
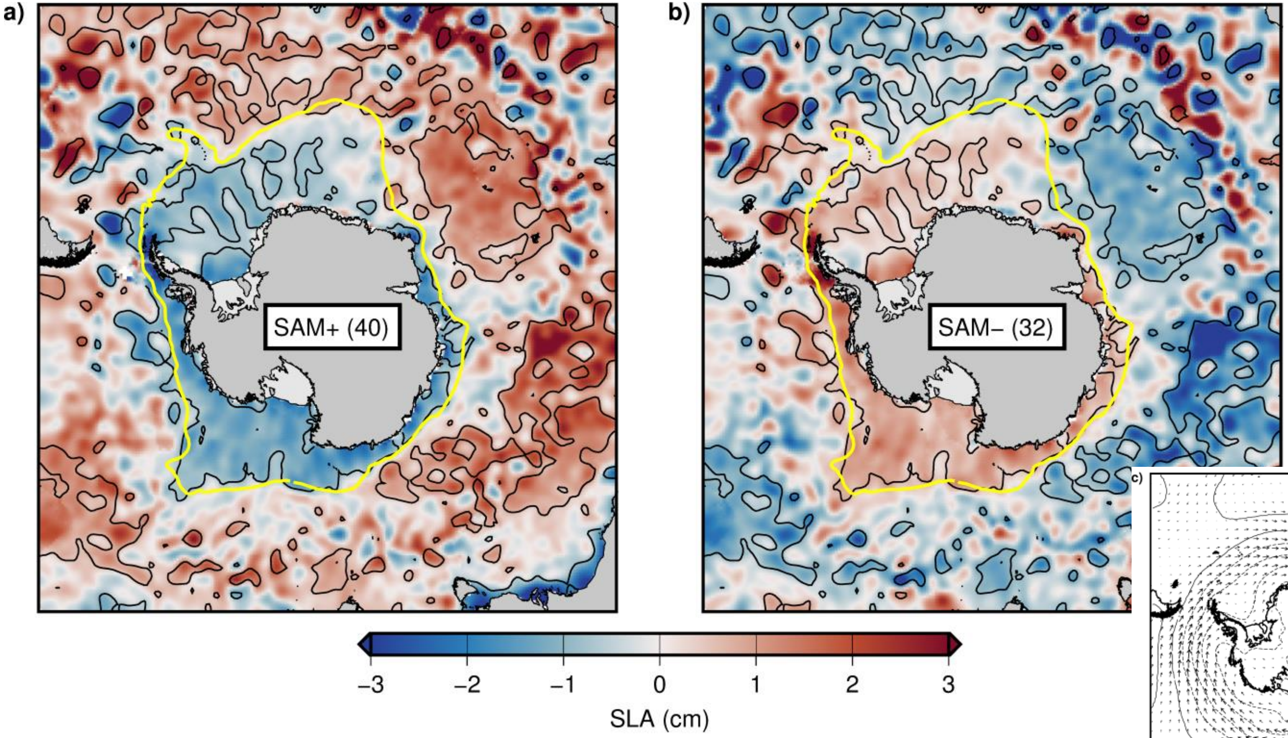




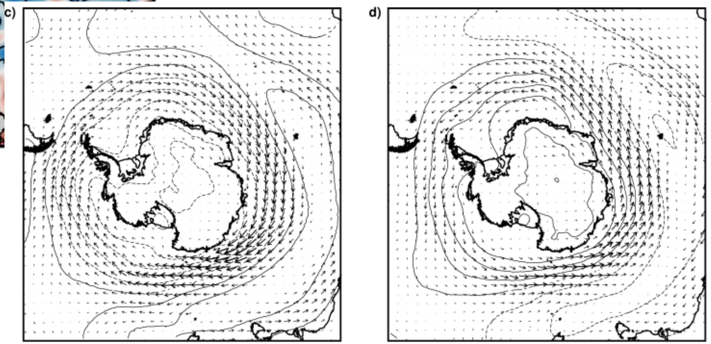
Results: Climate forcing

- Construct sea level anomaly composites for two major modes of SH climate variability:
  - Southern Annular Mode (SAM)
  - El Niño Southern Oscillation (SOI)

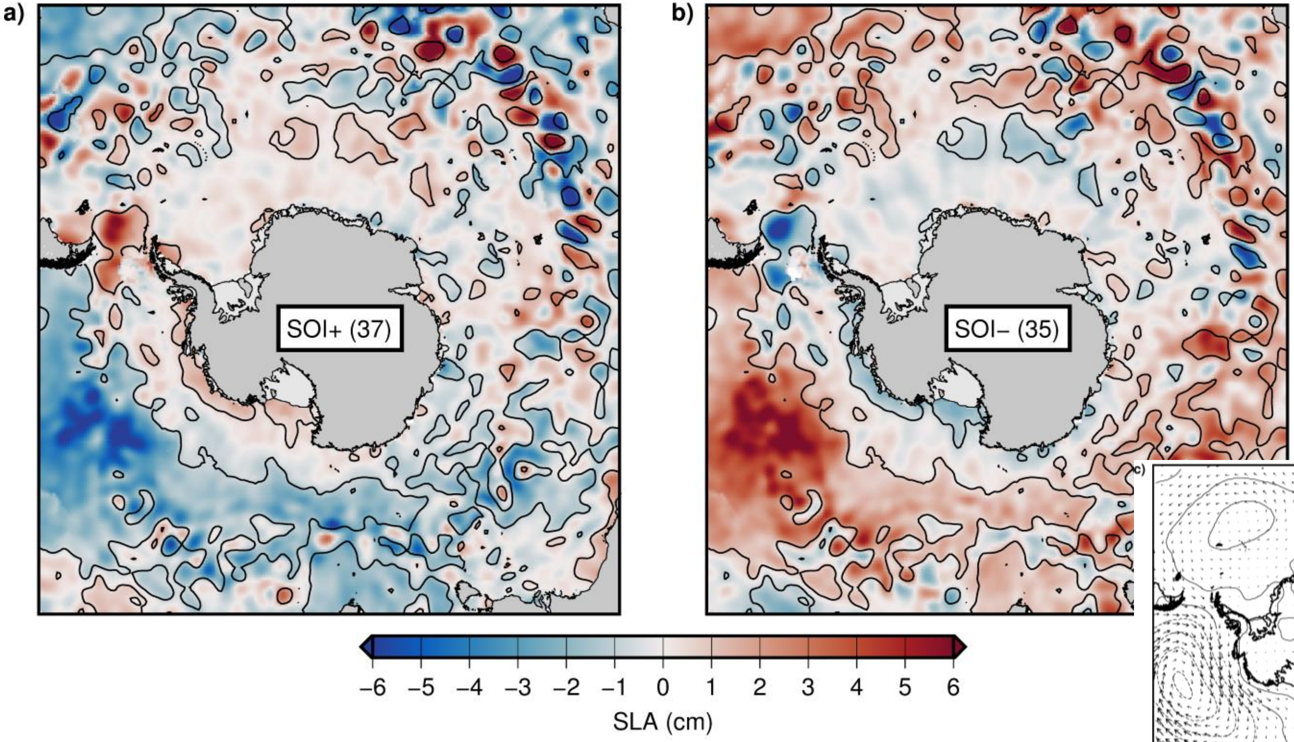
Results: Climate forcing



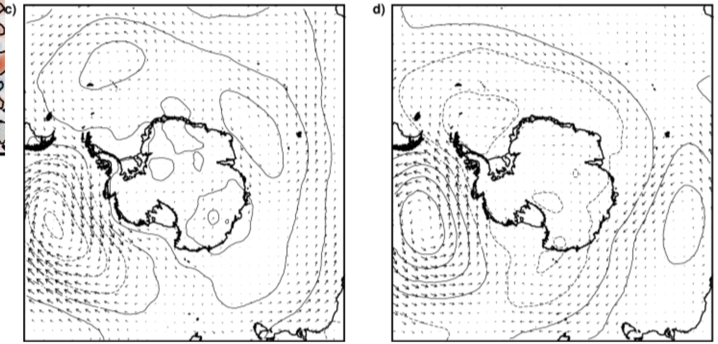
Southern Annular Mode composites



Results: Climate forcing

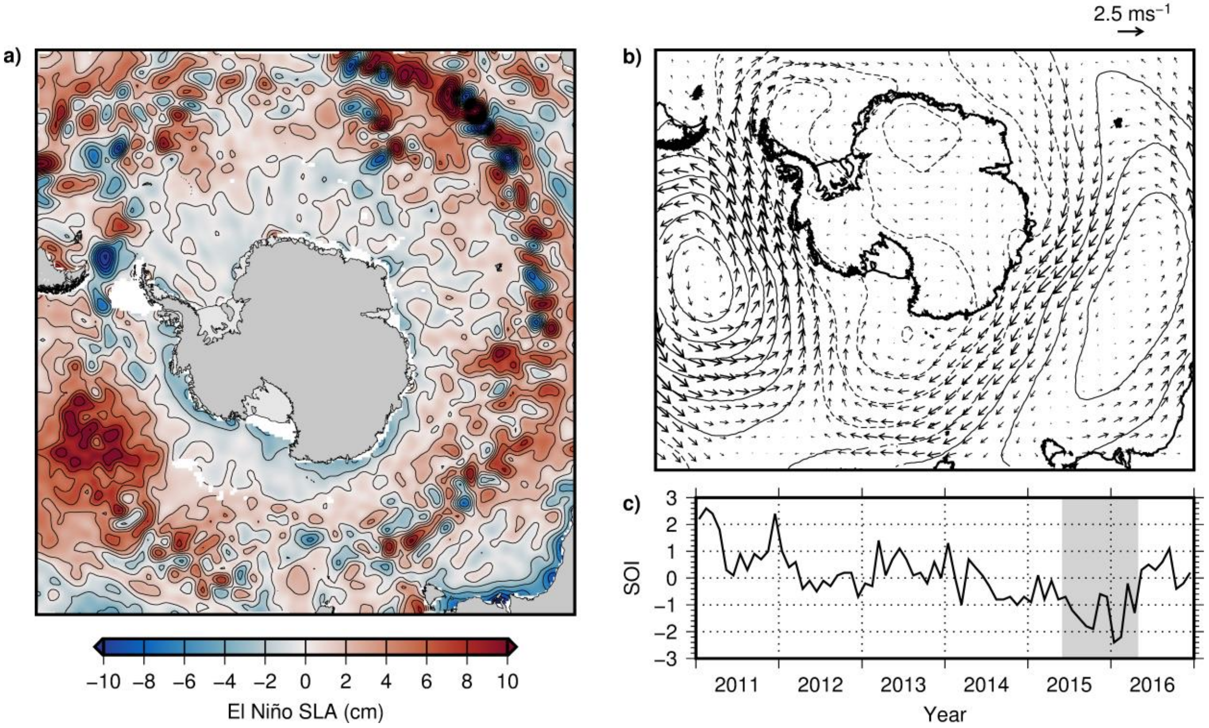


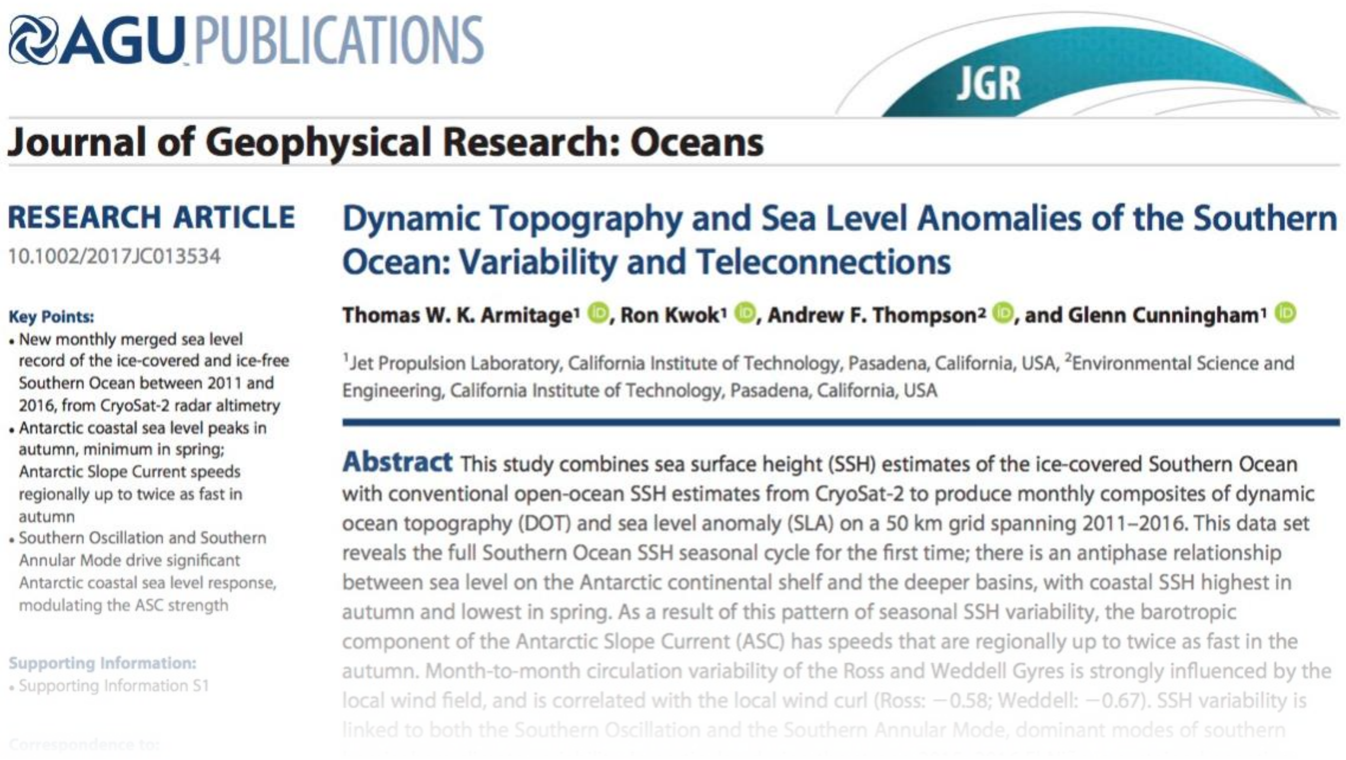
Southern Oscillation composites



Results: Climate forcing

- Negative coastal sea level anomalies observed during 2015-16 El Niño event
- Corresponds to weakening of ASC
  - Shoaling of isopycnals?





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RESEARCH ARTICLE

10.1002/2017JC013534

Key Points:

- New monthly merged sea level record of the ice-covered and ice-free Southern Ocean between 2011 and 2016, from CryoSat-2 radar altimetry
- Antarctic coastal sea level peaks in autumn, minimum in spring; Antarctic Slope Current speeds regionally up to twice as fast in autumn
- Southern Oscillation and Southern Annular Mode drive significant Antarctic coastal sea level response, modulating the ASC strength

Supporting Information:

- Supporting Information S1

Correspondence to:

Dynamic Topography and Sea Level Anomalies of the Southern Ocean: Variability and Teleconnections

Thomas W. K. Armitage[1], Ron Kwok[1], Andrew F. Thompson[2], and Glenn Cunningham[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [2]Environmental Science and Engineering, California Institute of Technology, Pasadena, California, USA

Abstract This study combines sea surface height (SSH) estimates of the ice-covered Southern Ocean with conventional open-ocean SSH estimates from CryoSat-2 to produce monthly composites of dynamic ocean topography (DOT) and sea level anomaly (SLA) on a 50 km grid spanning 2011–2016. This data set reveals the full Southern Ocean SSH seasonal cycle for the first time; there is an antiphase relationship between sea level on the Antarctic continental shelf and the deeper basins, with coastal SSH highest in autumn and lowest in spring. As a result of this pattern of seasonal SSH variability, the barotropic component of the Antarctic Slope Current (ASC) has speeds that are regionally up to twice as fast in the autumn. Month-to-month circulation variability of the Ross and Weddell Gyres is strongly influenced by the local wind field, and is correlated with the local wind curl (Ross: −0.58; Weddell: −0.67). SSH variability is linked to both the Southern Oscillation and the Southern Annular Mode, dominant modes of southern

Any questions?

Jet Propulsion Laboratory
California Institute of Technology

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